BOLE VOLUME GROWTH IN STEMS OF *QUERCUS GAMBELII*

Warren P. Clary[1] and Arthur R. Tiedemann[2]

ABSTRACT.—Shrub-form and tree-form Gambel oak (*Quercus gambelii*) stands contain a potentially significant fuelwood resource. Information on their growth characteristics can form a basis for future stand management. Stem analyses showed that height growth of shrub-form stems essentially ceased after age 50, while tree-form stems continued to increase in height until approximately age 100. Both stem forms continued to increase in basal area and volume at a relatively constant rate as the stems increased in age and size. Increases in all size measures were substantially greater in tree-form stems than in shrub-form stems. Mean bole volume for tree-form stems at age 100 was over 16 times that of shrub-form stems. Sprouts from tree-form stands would reach minimum size for fuelwood marketing in approximately 45 years.

Key words: *Gambel oak, Quercus gambelii, shrub-form, tree-form, height growth, volume growth.*

Gambel oak (*Quercus gambelii*) is a species important for wildlife habitat, watershed protection, and fuelwood. It is found in many areas of Arizona, Colorado, New Mexico, and Utah. In Utah the optimum elevations are 1700–2300 m where Gambel oak is a dominant in the Mountain Brush or mountain mahogany–oak shrub potential natural vegetation zone (Kuchler 1964, Harper et al. 1985, West 1989).

Gambel oak has a variable growth form. Normally a tall shrub or small tree, it can be found as dense, shrubby patches 1 m tall, or as widely spaced trees up to 23 m tall (Clary and Tiedemann 1986). This morphological variation prompted early taxonomists to recognize as many as eight additional species within populations now considered Gambel oak (Harper et al. 1985). The variability may have an environmental source (Neilson and Wullstein 1983), a genetic source (Pendleton et al. 1985), or both.

Sexual reproduction is sporadic, generally with limited success (Cottam et al. 1959, Neilson and Wullstein 1983, Wullstein and Neilson 1985). However, the species has a high regenerative capacity from adventitious buds situated on the lignotubers and rhizomes of existing clones (Muller 1951, Tiedemann et al. 1987). These buds give rise to numerous sprouts, particularly if fire, herbicides, woodcutting, or charring has killed the aboveground stem (Engle et al. 1983).

Gambel oak is particularly desirable as fuelwood because of its heat-yielding qualities—approximately 1.4 times greater than ponderosa pine (Barger and Ffolliott 1972). The superior heat-producing qualities of this species and its proximity to several major population centers have generated considerable interest in management and use of Gambel oak for fuelwood (Harper et al. 1985, Betters 1986). Retail prices reflect the heat-producing value of Gambel oak. It is typically sold for $10 more per ton than any other species (Johnson and Grosjean 1980).

Some information is available on projected growth characteristics of Gambel oak based primarily on diameter increments (Wagstaff 1984). However, no information is known to be available on the incremental growth of Gambel oak bole volumes. Because of this, we conducted this study to determine the volume growth characteristics of Gambel oak stems to assist in future management of this often ignored, but locally important, species.

METHODS

FIELD METHODS.—The plant materials for this study were collected as part of earlier studies of standing crop biomass (Clary and Tiedemann 1986, 1987). Eight small tree- and shrub-form plots were sampled within typical stands on Bald Mountain near Ephraim, Utah.

[1] ... S. Department of Agriculture, Boise, Idaho 83702. Correspond with this author at his present address: ... Boise 83702.
[2] ... Department of Agriculture, La Grande, Oregon 97850.

TABLE 1. Growth curve[1] coefficients and R^2's.

Stem form	Variables		Coefficient term				R^2
	Y	X	A	B	C	D	
Shrub	Basal area	Age	844.992	.439716	.004586	355.440	0.56
Tree	Basal area	Age	330.944	.762575	.022552	56.4056	0.58
Shrub	Volume	Age	574601.	.546456	.002810	542.712	0.68
Tree	Volume	Age	169008.	.546096	.011471	76.9049	0.55
Combined	Volume	Basal area	223504	.386965	.002732	173.616	0.94
Shrub	Height	Age	4.11932	1.09578	.026754	-27.2519	0.78
Tree	Height	Age	9.71913	.819354	.037815	19.0701	0.85
Shrub	Annual incr.	Volume	1363.82	-.053448	.000016	-3426.45	0.75
Tree	Annual incr.	Volume	2409.61	.242472	.000009	-24327.8	0.80

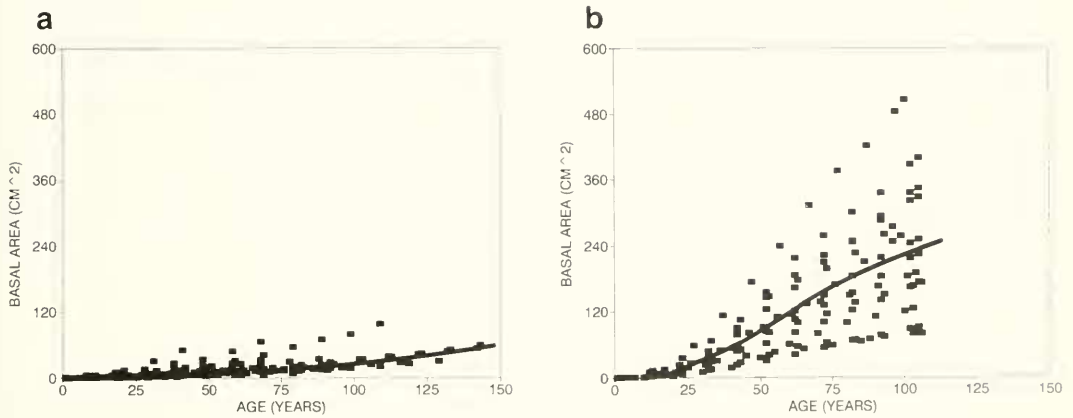[1]Model $Y = A^*(1 + (B - 1)^*EXP(-C^*(X - D))^\wedge(1/1 - B))$

Fig. 1. Basal area (cm^2) versus age (years): a, shrub-form stems; b, tree-form stems.

These are hereafter referred to as *shrub-form*. The sample stands were on slopes of up to 40%. The plots sampled varied in size from 3 × 3 m for high densities of small stems to 9 × 9 m for plots of less dense stems. Large Gambel oak trees were represented by five stands in the Cascade Springs area of the Uinta National Forest, Utah. These are referred to as *tree-form*. Tree-form stands were visibly distinct from surrounding vegetation and occupied concave slope positions where soil depth and moisture favored tree growth. Stands had to be of sufficient size to accommodate a 100-m^2 plot. Plots were square when possible, otherwise rectangular.

Stems greater than 1 m high were counted, numbered, and measured for diameter at a height of 4 cm. Three (in tree-form plots) or five (in shrub-form plots) trees were selected at random for sampling. Stem boles were cut 4 cm above ground line and separated from branches and foliage. Where the tree bole forked, the largest fork was selected as the main bole. These boles were partitioned into 60-cm sections continuing upward until stem diameter outside-bark had decreased to approximately 1 cm. The last sections were therefore of variable length. A 10-cm length was removed from the base of each section for tree-ring analysis by the late Dr. C. Wes Ferguson and associates, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

LABORATORY METHODS.—The basic approach of ring-count dating was augmented in this study by the use of dendrochronological techniques. In instances where the ring pattern was obscured or distorted, two types of controls were used to reconstruct the radial tree-ring sequence. First, a comparison was made with other areas of the cross section, with other sections from the same tree, or with other trees. The second, using
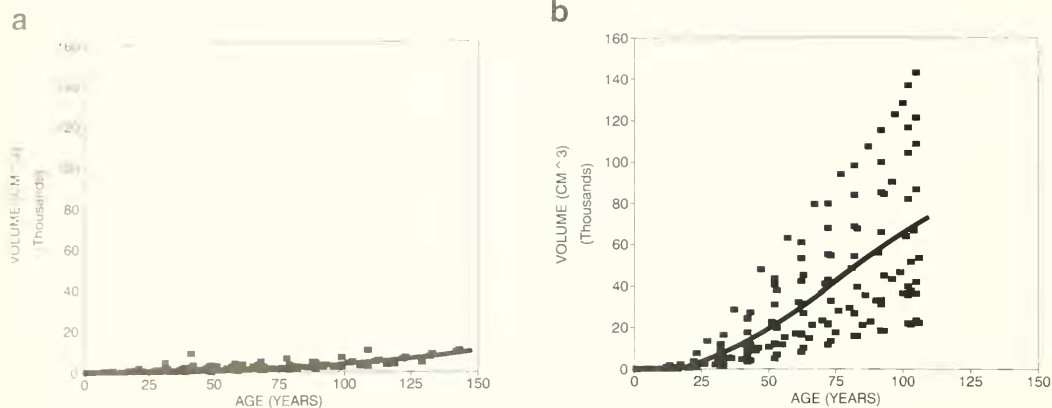
a

b

Fig. 2 Volume (cm³) versus age (years): a, shrub-form stems; b, tree-form stems.

dendrochronological principles, was to date all, or a portion thereof, of the radius in comparison with two relatively nearby established tree-ring chronologies—Nine Mile Canyon and Emory-Link. Several notable reference points were a pair of large rings at 1957 and 1958, and in some instances a wide band of vessels occurred in the 1919 ring. Some data had to be reconstructed for individual bole sections because of tree damage from fire or other injury, distortion due to whorls, etc. The diameter increments were determined to the nearest millimeter by decades, e.g., 1980–1971, progressing from the outer ring of the stem toward the pith. Partial decade growth was recorded when the beginning or ending of the section growth record fell within a decade. As the stems tended to be asymmetrical, the longest and shortest inside bark radii were recorded.

Cross-sectional area and volume calculations were made by using spreadsheet software on a personal computer. Diameter and volume values were calculated on an air-dry, inside-bark basis. The cross-sectional area for a given period was determined for both ends of each section using the longest and shortest radii and assuming an elliptical shape. Section volume for each period, usually decadal, was calculated from the top and bottom cross-sectional areas for the period and the section length using the paraboloid method. Period (usually decadal) volumes were summed across sections to give stem volume totals per period. Bole heights were determined by summing the section lengths. Heights at a given age were estimated in the manner of Lenhart (1972); relative annual growth tips are

assumed to be equally spaced throughout the section. Patterns of volume change were examined by graphic and regression methods, using periods or height segments within trees as sample units to illustrate growth trends. All regression fits were made using the Richards growth curve model (Richards 1959).

RESULTS

Little data overlap occurred between the two populations above age 30 in the basal area versus age relationships (Figs. 1a, 1b, Table 1). At age 30 tree-form stems had mean basal area values nearly 10-fold those of shrub-form stems. Similar relationships occurred with volume versus age (Figs. 2a, 2b, Table 1). At age 100 mean stem volumes were 4049 cm³ and 65,808 cm³ for shrub-form and tree-form, respectively, or a difference exceeding 16-fold.

The relationship of volume to basal area was more consistent between stem forms than in the previously described relationships. A single function fit the full range of data for both populations combined (Fig. 3, Table 1).

Relationships of height to age varied between the two populations. Rates of height growth were not greatly different among populations for the first 20 years. After 50 years, however, little additional height increment occurred on shrub-form stems (Fig. 4a, Table 1). Maximum height averaged 4.1 m. Tree-form stems continued growth after age 50 at substantial, although slowly decreasing, rates until approximately 9.3 m in height was attained at age 100 (Fig. 4b, Table 1).
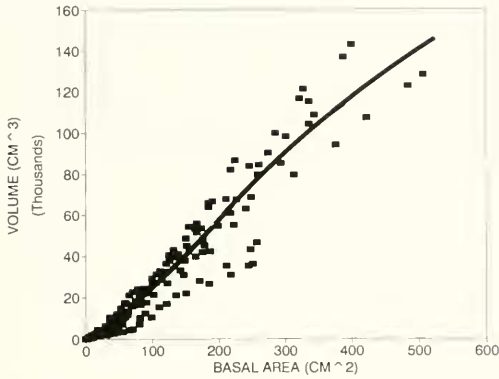
Fig. 3. Volume (cm³) versus basal area (cm²) for combined stem forms.
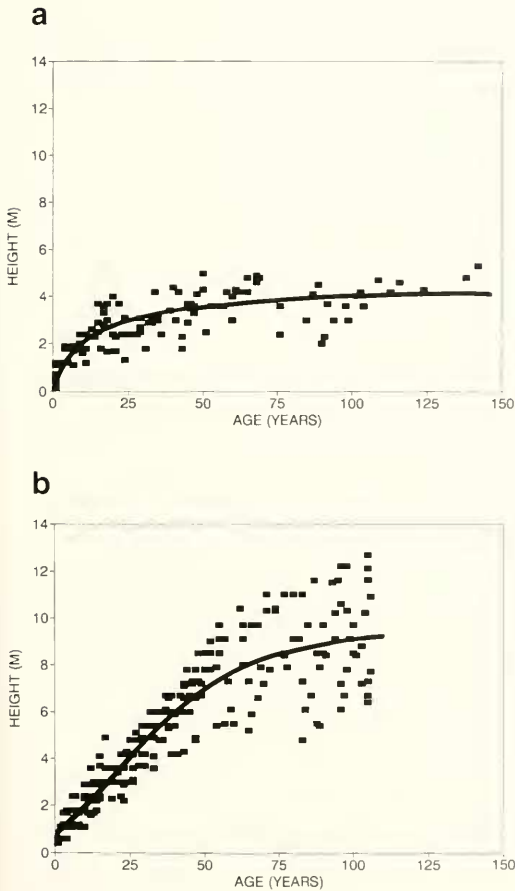
a

b

Fig. 4. Height (m) versus age (years): a, shrub-form stems; b, tree-form stems.

The relationship between annual volume increment and age was not strong for either population: R^2 values were .29–.38. A better fit was obtained between annual volume increment and total volume ($R^2 = .75$–.80). Annual volume increment as a function of existing volume was greater at all volumes in tree-form stems than in shrub-form stems, illustrating more vigorous growth (Figs. 5a, 5b, Table 1).

DISCUSSION

Sampling in this study was limited to central Utah, but stem sizes encountered were representative of sizes across the distribution of Gambel oak. Mean basal diameters of the stands in this study varied from 3.6–11.7 cm in shrub-form stems to 15.1–24.6 cm in tree-form stems (Clary and Tiedemann 1986, 1987). Our shrub-form stems, therefore, corresponded to the average 7.6-cm stump height diameters in western Colorado (Brown 1958). Our tree-form stems were similar in diameter to the larger stems in north central Arizona (Barger and Ffolliott 1972).

Limited information has been available concerning direct volume measures or growth characteristics of Gambel oak. A volume table based on a technique of visually estimated volume is available for Colorado (Chojnacky 1985), and one has been used in Arizona that was developed by modifying a composite volume table for trees in the Great Lakes vicinity (Barger and Ffolliott 1972). Barger and Ffolliott (1972) found that annual stand volume growth in Arizona averaged 0.24 m³/ha, or about a 2% increment. A similar percentage increment was found in Utah for individual older trees (Wagstaff 1984). Wagstaff's (1984) data showed that diameter growth in tree-form stems slowed little in older trees; thus, the rate of basal area accumulation increased with age. In this study our estimates of annual growth in older tree-form stems were similar to those of Wagstaff, although differences in magnitude between shrub-form and tree-form stems were striking in nearly all data collected. Basal area versus age, volume versus age, height versus age, and annual volume increments in relation to total volume were different between stem forms. Volume versus basal area was the only relationship examined that appeared similar between stem forms.
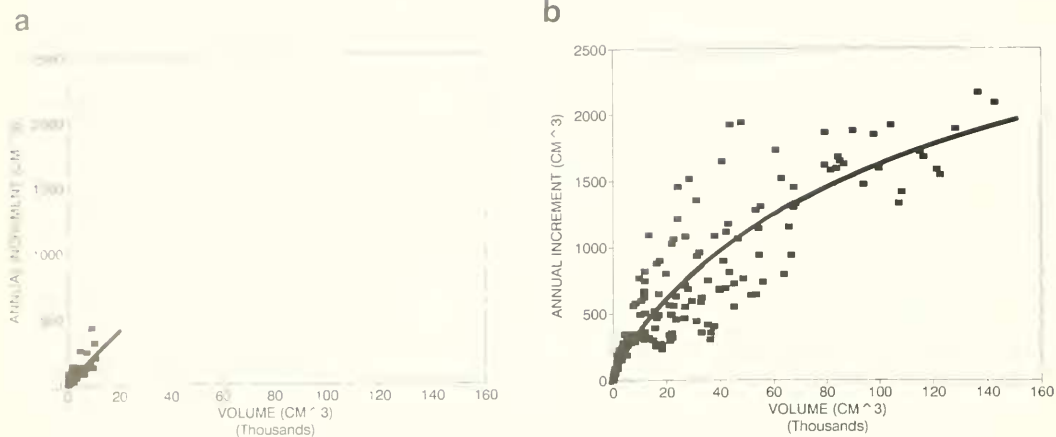
Fig. 5. Annual volume increment (cm³) versus volume (cm³): a. shrub-form stems; b. tree-form stems.

A massive underground structure, which supports rapid and normally voluminous sprouting following top removal, provides a reliable reproduction strategy that should fit well into a coppice fuelwood management cycle of harvest and regrowth (Clary and Tiedemann 1986, Tiedemann et al. 1987). This would be especially true on the more productive sites where clones of tree-form stems or larger shrub-form stems are available. While we can offer no direct evidence that tree-form stands will coppice to new tree-form stands rather than to shrub-form stands, circumstantial evidence suggests this is so. Tree-form stands in this study were separated by a distance of several kilometers; yet most of the stems of these stands were established within a 3-year period. The most likely cause would be sprouting following a widespread hot wildfire. Sprouting following such events typically results in high stem densities. As the new stand ages, a natural thinning occurs. This is reflected in old stem scars on lignotubers and rhizomes (Tiedemann et al. 1987). Scars of previous stems and the underground interconnected mass of Gambel oak clones suggest that generations of stems arise repeatedly from the underground structures. These stems would reflect the same genetic makeup as the previous stem and would be growing on the same site.

Here the potential of mature stands near cities and towns is substantial. Maximum retail value would approach $55,000/ha of oak clone if individuals on these valuable Utah sites are completely harvested (Wagstaff 1984). Arizona forests have marketable Gambel oak volumes of 16

m³/ha averaged across broad clone-occupied and non-clonal areas (Barger and Ffolliott 1972). The retail value on a landscape basis, therefore, would be $740/ha (1983 dollars) if all harvestable volume were removed (Wagstaff 1984).

Gambel oak is marketable when average diameters are relatively small. Wagstaff (1984) reported that stems are salable as fuelwood when the basal diameter reaches about 9 cm (basal area of 64 cm²). This diameter, based on our stem analyses, would be attained in 45 years in our unmanaged tree-form stands. A few shrub-form stems would reach marketable size in 90 to 100 years, but a projected 170 years would be required in our average unmanaged shrub-form stands.

Our current (mature) tree-form stands with marketable volumes of 150.6–604.6 m³/ha would be worth $11,144–$44,740 per hectare of clone (Wagstaff 1984, Clary and Tiedemann 1987). Marketing of the resulting sprout growth could occur in approximately 45 years, although volumes would be much less than the original harvest. Estimated volume at age 45 would be only 25% of that attained at age 100.

Only one of our shrub-form stands had average stem diameters of marketable size, although four of the eight stands had some stems that exceeded the 9-cm-diameter requirement. The stands had mean bole volumes of 46.6–94.1 m³/ha and no apparent correlation between volume and stand density, although lower density stands tended to have larger stems. Thus, values for those stands that have attained marketable

diameters could be $3448–$6963 per hectare of clone (Clary and Tiedemann 1986, Wagstaff 1984). Any estimate of marketability and value for a specific oak stand would, however, have to be determined on site.

Fuelwood sales can provide a valuable tool for oak stand management. Fuelwood cutting can generate revenue while achieving various stand modification goals, such as modifying wildlife habitat conditions (Reynolds et al. 1970) or stimulating sprouts in over-mature stands for future fuelwood production.

LITERATURE CITED

BARGER, R. L., AND P. F. FFOLLIOTT. 1972. Physical characteristics and utilization of major woodland tree species in Arizona. USDA Forest Service Research Paper RM-83. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. 80 pp.

BETTERS, D. R. 1986. Gambel oak in Colorado's Front Range. Pages 25–30 in P. F. Ffolliott and W. T. Swank, eds., Potentials of noncommercial forest biomass for energy. Technical Bulletin 256, School of Renewable Natural Resources, University of Arizona, Tucson.

BROWN, H. E. 1958. Gambel oak in west-central Colorado. Ecology 39: 317–327.

CHOJNACKY, D. C. 1985. Pinyon-juniper volume equations for the central Rocky Mountain States. USDA Forest Service Research Paper INT-339. Intermountain Forest and Range Experiment Station, Ogden, Utah. 27 pp.

CLARY, W. P., AND A. R. TIEDEMANN. 1986. Distribution of biomass within small tree and shrub form Quercus gambelii stands. Forest Science 32: 234–242.

_____. 1987. Fuelwood potential in large-tree Quercus gambelii stands. Western Journal of Applied Forestry 2: 87–90.

COTTAM, W. P., J. M. TUCKER, AND R. DROBNICK. 1959. Some clues to Great Basin postpluvial climates provided by oak distributions. Ecology 40: 361–377.

ENGLE, D. M., C. D. BONHAM, AND L. E. BARTEL. 1983. Ecological characteristics and control of Gambel oak. Journal of Range Management 36: 363–365.

HARPER, K. T., F. J. WAGSTAFF, AND L. M. KUNZLER. 1985. Biology and management of the Gambel oak vegetative type: a literature review. USDA Forest Service General Technical Report INT-179. Intermountain

Forest and Range Experiment Station, Ogden, Utah. 31 pp.

JOHNSON, C. M., AND M. J. GROSJEAN. 1980. Wood for heating Utah homes, an asset or liability? Publication EL 95. Cooperative Extension Service, Utah State University, Logan. 9 pp.

KUCHLER, A. W. 1964. Manual to accompany the map: potential natural vegetation of the conterminous United States. American Geographical Society Special Publication 36. New York, New York. 39 pp.

LENHART, D. J. 1972. An alternative procedure for improving height/age data from stem analysis. Forest Science 18: 332.

MULLER, C. H. 1951. The significance of vegetative reproduction in Quercus. Madroño 11: 129–137.

NEILSON, R. P., AND L. H. WULLSTEIN. 1983. Biogeography of two Southwest American oaks in relation to atmospheric dynamics. Journal of Biogeography 10: 275–297.

PENDLETON, R. L., S. C. SANDERSON, AND E. D. MCARTHUR. 1985. Morphologic and enzymatic variability among Gambel oak clones in northcentral Utah. Pages 19–28 in K. L. Johnson, ed., Proceedings of the third Utah Shrub Ecology Workshop. College of Natural Resources, Utah State University, Logan.

REYNOLDS, H. G., W. P. CLARY, AND P. F. FFOLLIOTT. 1970. Gambel oak for southwestern wildlife. Journal of Forestry 68: 545–547.

RICHARDS, F. J. 1959. A flexible growth function for empirical use. Journal of Experimental Botany 10: 290–300.

TIEDEMANN, A. R., W. P. CLARY AND R. J. BARBOUR. 1987. Underground systems of Gambel oak (Quercus gambelii) in central Utah. American Journal of Botany 74: 1065–1071.

WAGSTAFF, F. J. 1984. Economic considerations in use and management of Gambel oak for fuelwood. USDA Forest Service General Technical Report INT-165. Intermountain Forest and Range Experiment Station, Ogden, Utah. 8 pp.

WEST, N. E. 1989. Vegetation types of Utah. Pages 18–56 in K. L. Johnson, ed., Rangeland resources of Utah. Cooperative Extension Service, Utah State University, Logan.

WULLSTEIN, L. H., AND R. P. NEILSON. 1985. Seedling survival and biogeography of Gambel oak (Quercus gambelii) in northern Utah. Pages 1–3 in K. L. Johnson, ed., Proceedings of the third Utah Shrub Ecology Workshop. College of Natural Resources, Utah State University, Logan.